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# Optimization of Kinematic Characteristics of Geneva Mechanism

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*In this paper, the possibility of introducing variable angular velocity of a driving wheel is considered, with the purpose of optimization of kinematical characteristics of Geneva mechanism. The purpose is to reduce the rise that occurs at angular acceleration of Geneva wheel during engagement and disengagement, while angular velocity of the driving wheel remains limited. Kinematical analysis of this mechanism is performed. Expressions for angular velocity and angular acceleration of Geneva wheel are obtained. Optimization of the polynomial parameters of the law of the rotation angle of the driving wheel is performed.*

**Keywords: Geneva mechanism, optimization, driving wheel, acceleration, kinematical analysis.**

## 0 INTRODUCTION

In designing various machines and devices, the need for implementation of motion with intermittent motion often occurs, where the relation between operating time and time of inaction is a given size. This kind of motion can be implemented by using Geneva mechanism. The basic division of these mechanisms is into mechanisms with external and internal coupling, even though they can also be spherical, where axes of inlet and outlet shaft are passing by perpendicularly**.** Without the loss of generality, we will consider kinematical characteristics of Geneva mechanism with external coupling, which is most frequently considered in scientific papers.

This mechanism is not appropriate for use when angular velocities of the driving wheel are high because then the rise of angular acceleration of Geneva wheel occurs during engagement and disengagement from a coupling with the driving wheel.

Many papers are dedicated to solving this problem. Fenton [2] presented a method based on graphs for calculating the forces and torques acting on various parts of the mechanism. Fenton and Wu [3] calculated the dynamic, static forces and deformations of the Geneva wheel using the finite element method. Fenton et al. [4] transformed the slots of a Geneva wheel to a curved shape and eliminated the non-zero initial and final accelerations. Takanashi [5, 6] analyzed the error of the output motion induced by the manufacturing tolerances and clearances. Cheng C., Yui L., [7] suggested that nonlinear elastic element is introduced between the pin on a driving wheel and slot wall of Geneva wheel, in order to reduce the rise of acceleration that occurs. Sujan ad Meggiolaro [8] modified driving wheel of this mechanism, that is, four-bar linkage was introduced instead, in order to provide an appropriate variable entry by choosing the lengths of the wheels of this mechanism. Lee and Cho used optimal control method to improve kinematic characteristics of Geneva wheel [9]. Heidari et all [1] used the idea of variable input velocity of the mechanism in order to obtain the desired kinematical characteristics of the mechanism. They assumed that the law of rotation angle of the driving wheel could be written in the form of the $7^{th}$ degree polynomial, so by using genetic algorithm they conducted the optimization of parameters of this polynomial in order to obtain the reduction of the maximum of angular acceleration of Geneva wheel, as well as a jerk that occurs then. However, as far as angular velocity of the driving wheel is concerned, the authors did not introduce limitations.

In this paper, optimization will be conducted, with the purpose of reducing the angular acceleration of Geneva wheel, and the attention will be paid that angular acceleration of the driving wheel is within the corresponding boundaries. The achieved results will be compared to the results obtained in the paper [1].

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## 1. KINEMATICAL ANALYSIS

Basic elements of Geneva mechanism are driving wheel 1 with pin 2, and slotted wheel 3 which contains z equally spaced radial slots.

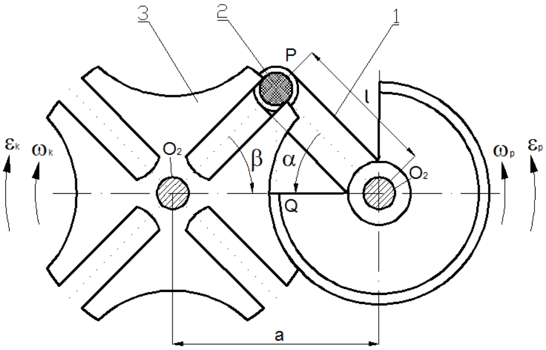


Fig. 1 *Geneva mechanism with four slots*

The number of slots z can be from 3 to 15, but mechanisms with more than 9 slots are seldom used. It is because the length of the driving wheel needs to be small, and a very large torque is required to drive the wheel. Without loss of generality, we are to consider kinematical characteristics of the 4- slot mechanism.

Fig. 1 shows basic geometrical sizes of this mechanism. It can be observed:

$$tg\beta = \frac{\overline{PQ}}{\overline{O_2Q}} = \frac{l\sin\alpha}{a - l\cos\alpha}, \tag{1}$$

that is,

$$\beta = arctg\frac{l\sin\alpha}{a - l\cos\alpha}, \tag{2}$$

Angular velocity of Geneva wheel is:

$$\omega_k = \frac{d\beta}{dt} = \lambda\dot{\alpha}\frac{\cos\alpha - \lambda}{1+\lambda^2 - 2\lambda\cos\alpha}, \tag{3}$$

where λ is obtained on the basis of condition that at the beginning of coupling a shock does not occur, that is, $\overline{O_1P} \perp \overline{O_2P}$, that is:

$$\lambda = \frac{l}{a} = \frac{l}{l\sqrt{2}} = \frac{\sqrt{2}}{2}, \tag{4}$$

By differentiation of expression (3) according to time, expression for angular acceleration of Geneva wheel is obtained:

$$\varepsilon_k = \ddot{\beta} = \lambda\ddot{\alpha}\frac{\cos\alpha - \lambda}{1+\lambda^2 - 2\lambda\cos\alpha} - \lambda\dot{\alpha}^2\sin\alpha\frac{1-\lambda^2}{\left(1+\lambda^2 - 2\lambda\cos\alpha\right)^2}, \tag{5}$$

Let's define following dimensionless parameters:

$$T = \frac{t}{\tau}, \tag{6}$$

$$A = \frac{\alpha}{\pi/2}, \tag{7}$$

According to the relations (6) and (7), the following applies:

$$\alpha(t) = \frac{\pi}{2}A(T), \tag{8}$$

$$\dot{\alpha}(t) = \frac{\pi}{2\tau}\dot{A}(T), \tag{9}$$

$$\ddot{\alpha}(t) = \frac{\pi}{2\tau^2}\ddot{A}(T), \tag{10}$$

where,

$$\dot{\alpha}(t) = \frac{d\alpha}{dt}, \dot{A}(T) = \frac{dA}{dT},\ t\in[0,\tau],\ \alpha\in[0,\frac{\pi}{2}].$$

Therefore, $T$ vary between 0,1 and *A(T)* between -0,5 and 0,5.

By including relations (8), (9), (10) into expressions (3) and (5), the following is obtained:

$$\Omega_k = \frac{\lambda\pi}{2\tau}\dot{A}\frac{\cos\left(\frac{\pi}{2}A\right) - \lambda}{1+\lambda^2 - 2\lambda\cos\left(\frac{\pi}{2}A\right)}, \tag{11}$$

$$\mathrm{E}_k = \frac{\lambda\pi}{2\tau^2}\ddot{A}\frac{\cos\left(\frac{\pi}{2}A\right) - \lambda}{1+\lambda^2 - 2\lambda\cos\left(\frac{\pi}{2}A\right)} - \lambda\left(\frac{\pi}{2\tau}\dot{A}\right)^2\sin\left(\frac{\pi}{2}A\right)\frac{1-\lambda^2}{\left(1+\lambda^2 - 2\lambda\cos\left(\frac{\pi}{2}A\right)\right)^2}, \tag{12}$$

From previous expressions it is obvious that angular velocity and angular acceleration of Geneva wheel $\Omega_k$, and $E_k$, respectively, are hypersensitive to the variation of angular rotation $A(T)$. It can guide us to use input angular displacement to control output characteristics.

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### 1.1 Variable angular velocity of the driving wheel

It turned out that introducing of variable angular velocity of the driving wheel is efficient method for improvement of kinematical characteristics of the mechanism. We are to assume that the law of rotation angle of the driving wheel can be written in the form of 7th degree polynomial:

$$A(T) = \sum_{i=0}^{7} a_i T^i, \tag{13}$$

Figure 2 shows angular acceleration and angular speed of Geneva wheel, where $\dot{A} = 1$.

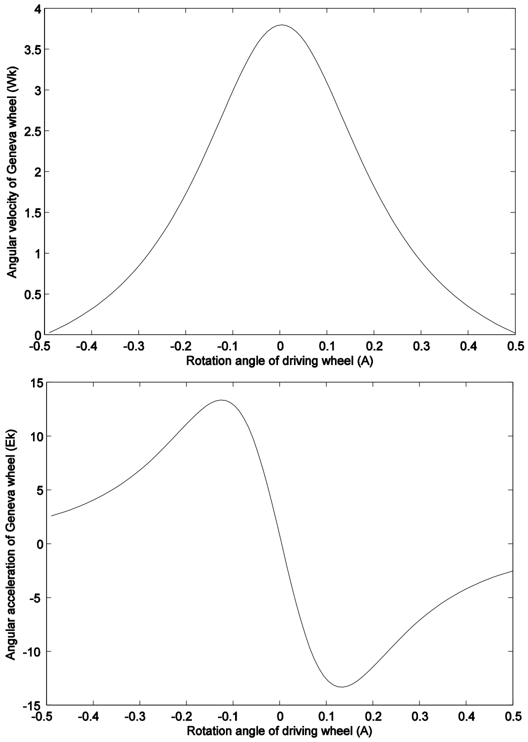


Fig.2 *Angular acceleration and angular velocity of Geneva wheel*

It is obvious that angular acceleration at the beginning and at the end of coupling is not equal to zero, so therefore, the occurrence of the shock is not possible. For that reason, angular acceleration of Geneva wheel needs to be obtained at the beginning of coupling and as low as possible. Aside from that, the equation (13) needs to satisfy the following boundary conditions.

$$A(0) = -0.5, \tag{14}$$

$$A(1) = 0.5, \tag{15}$$

$$\dot{A}(0) = 0, \tag{16}$$

$$\dot{A}(1) = 0, \tag{17}$$

## 2 OPTIMIZATION

In paper [1], the optimization of engagement polynomial parameter is conducted with the purpose of reducing the chosen acceleration of Geneva wheel. The law of angular change of the driving wheel is obtained in the following form:

$$A(T) = 0.65735T^7 - 1.33785T^6 + 0.19029T^5 + 1.63741T^4 - 0.2992T^3 - 1.4501T^2 + 1.6T - 0.5, \tag{18}$$

The obtained results are presented in the figure 3. The authors obtained reduction of maximum value of angular velocity for 40.5% and angular acceleration for 32.5%.

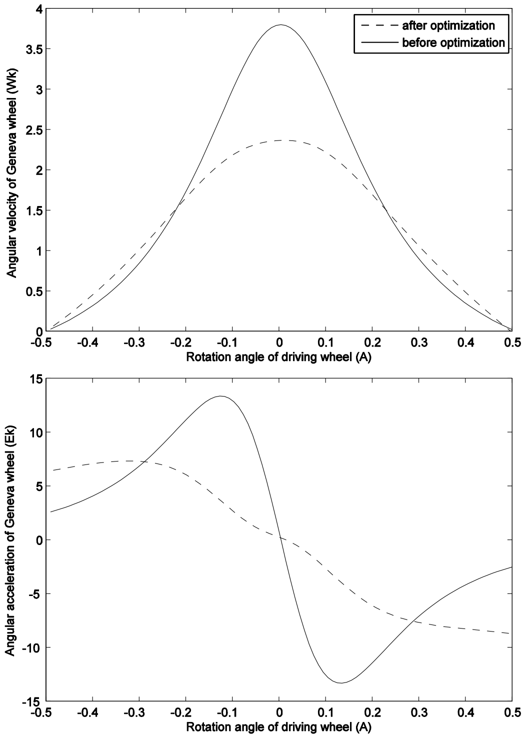


Fig. 3 *Kinematical characteristics of Geneva wheel before and after optimization*

The obtained results are satisfying. The figure 4 shows kinematical characteristics of the driving wheel accomplished after the optimization. It is observed that the driving wheel acceleration reaches the values $E_p(1) = 6.2\,[\,s^{-2}\,]$.

We are to conduct the new optimization procedure with the purpose of accomplishing reduction of angular acceleration $E_k(T)$ with the condition that inlet angular acceleration is $E_p(T) < 5\,[\,s^{-2}\,]$.

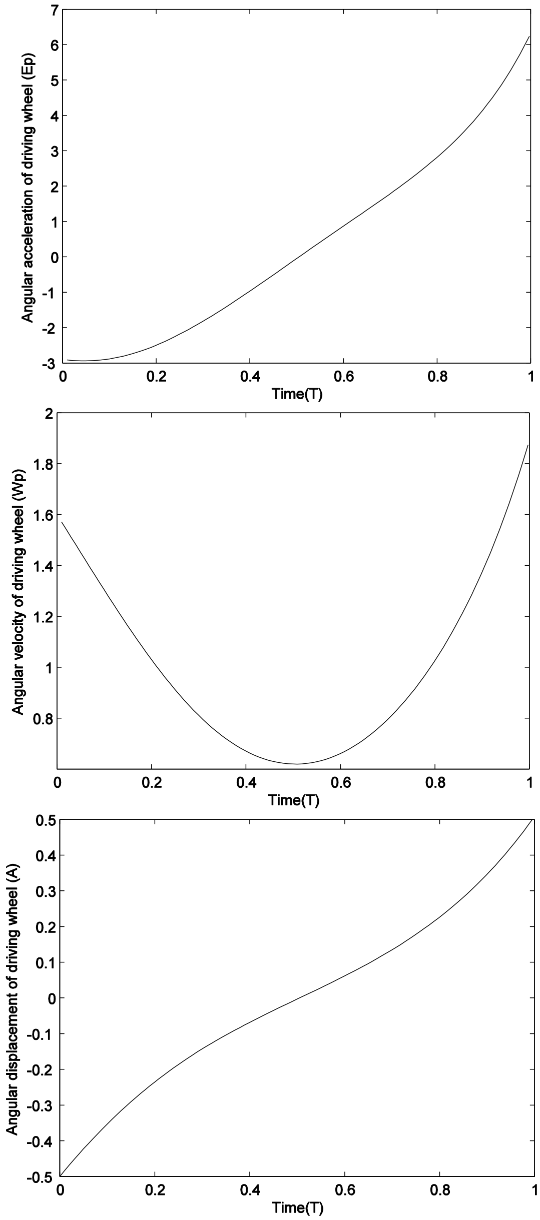


Fig. 4 *Kinematical characteristics of the driving wheel after the optimization*

## 2.1 Multicriteria optimization

In this paper, optimization is considered by setting up two criterial functions, one representing angular acceleration of Geneva wheel, and the other angular acceleration of the driving wheel. Values of these objective functions should be minimum in order to achieve better kinematical characteristics. Firstly, we are going to determine minimum values of each objective function, and after that, we are to form the final objective function in the form:

$$f = f_1(E_k - E_k^*) + f_2(E_p - E_p^*), \qquad (19)$$

whereby $E_k^*$ and $E_p^*$ are desired values of angular acceleration of Geneva wheel and driving wheel, and $E_k$ and $E_p$ are the functions of projective variables that ensue from the equation (13). Constraints are represented in the form of the equations (14), (15), (16) and (17).

In this paper the algorithm of Differential evolution (DE) [11, 12], which gives very efficient solution to the problem, is used during the optimization. Optimization parameters are polynomial coefficients that are used for defining the law of rotation angle of the driving wheel. Initial values of upper and lower variable boundaries are represented in Table 1. Likewise,parameters of algorithm are: NP=70 (population size),CR=0.9 (intersection constant ), F= 0.6 (mutation constant) and D=7 (the number of projective variables ).

| $i$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $a_{i\,min}$ | -2 | -2 | -2 | -2 | -2 | -2 | -2 |
| $a_{i\,max}$ | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Table 1. *Boundary values of polynomial parameters*

After conducted optimization procedure, we are to obtain the law of rotation angle of the driving wheel in the following form:

$$A(T) = 0.733520T^7 - 0.781195T^6 - 0.971799T^5 + 1.875107T^4 - 1.077826T^3 + 0.442468T^2 + 0.699640T - 0.5, \qquad (20)$$

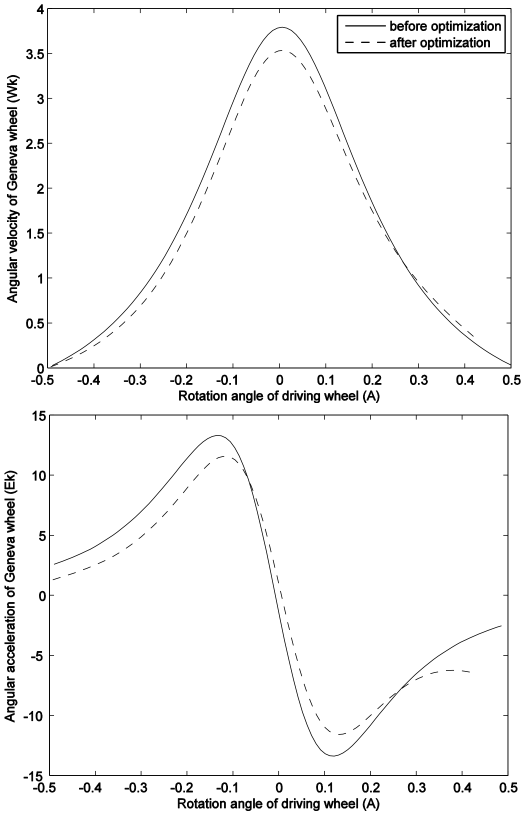


Fig. 5 *Kinematical characteristics of Geneva wheel before and after the optimization*

Fig. 5 represents kinematical characteristics of Geneva wheel, before and after conducted optimization. Maximum value of angular velocity is decreased from $3.8\,[s^{-1}]$ to $3.4\,[s^{-1}]$, that is, for 10.52 %, while maximum value of angular acceleration is decreased from the original $13.25\,[s^{-2}]$ to $11.4\,[s^{-2}]$ for 14%. Besides that, maximum value of angular acceleration of the driving wheel is decreased from previous $6.2\,[s^{-2}]$ to $4.8\,[s^{-2}]$ that is, for 22.6 %.

Fig. 6 represents comparative view of optimization results that are conducted in the paper [1] and in this paper. It is clear that by optimization in the paper [1] lower extreme values of angular velocity and angular acceleration of Geneva wheel are obtained, but the intensity of angular acceleration at the beginning of coupling is three times lower in the case of the second optimization. This fact is very significant, because the shocks at the beginning of coupling are significantly avoided by that. Besides, by using optimization in this paper it is achieved that maximum value of angular acceleration of the driving wheel is lower for $1.4\,[s^{-2}]$, that is ,for 22.6 %.

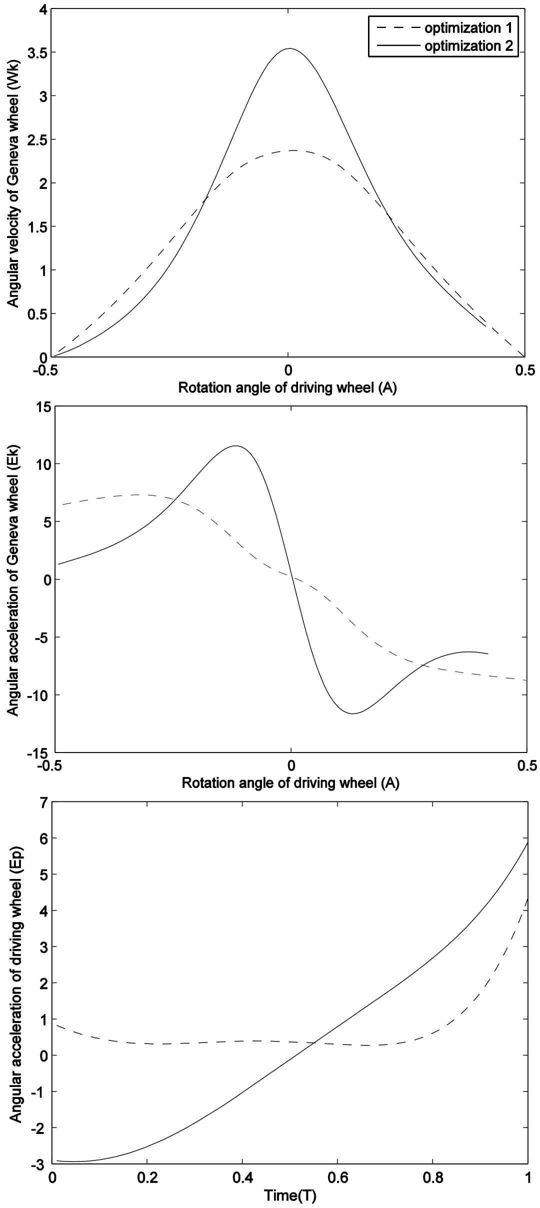


Fig. 6 *The comparison of the optimization results*

## 3. CONCLUSION

Based on the conducted optimization procedure we can observe that relatively small demands for reduction of maximum value of inlet acceleration (22.6%) maximum values of angular velocity (48%) of Geneva wheel increase when compared to the conducted procedure of optimization in the paper 1. However, given that the initial angular acceleration of Geneva wheel is considerably lower, as well as that we can influence the reduction of maximal values of angular acceleration of the driving wheel, these results are significant when for some reason angular acceleration of the driving wheel needs to be reduced.

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